Early steps towards modelling the phytoplankton-heat feedback

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Introduction

Phytoplankton in order to survive in the upper ocean carry out photosynthesis absorbing the solar radiation penetrating in the ocean. Thereby they also absorb heat.
High biomass during the *spring bloom* is thought to substantially affect the penetration of light and in turn heat in the upper ocean. The biological effect of this process has been extensively investigated and is described as the *Self Shading* effect.
However the possible physical effects on the thermal structure and therefore on stratification of the water column are still poorly understood.
Here we study the impact of marine biomass on ocean stratification and sea surface temperature (SST) using an Ocean General Circulation Model (OPA; Madec and Imbard, 1996; Madec et al., 1999) coupled to a Dynamic Green Ocean Model (Buitenhuis et al., this meeting; Aumont *et al*., 2003).

Method

In OPA the irradiance at each vertical level is computed following the Paulson & Simpson (1977) model, as follows:

$$I_{(z)} = I_o * (R * e^{(-z/\xi_1)} + (1-R) * e^{(-z/\xi_2)}) \quad (1)$$

Where R = 0.58, ξ_1 = 0.35 m, ξ_2 =23 m, corresponding to **Type I** waters (open ocean waters).
This approach is based only on the physical characteristics of seawater.
We aim to implement a new model including the effect of chlorophyll concentration on light penetration in the ocean.
We generally follow the approach of Morel & Antoine (1994) also adopted by other authors in previous modelling studies.
The light extinction coefficient is computed as function of the chlorophyll concentration:

$$K_{(\lambda)} = kw_{(\lambda)} + \chi_{(\lambda)} * [chl_{tot}]^{l(\lambda)} \quad (2)$$

Where $K_{(\lambda)}$, $kw_{(\lambda)}$, $\chi_{(\lambda)}$, $l_{(\lambda)}$ are respectively, the light extinction, the pure seawater absorption, pigment absorption and exponential coefficient for a single wavelength (λ). We adopt a two-band model rather than a full spectral model, which does not affect the results (Lefevre 2003, personal communication) and saves a lot of computational time.
The values of coefficients are reported in the table below:

Light Band	kw(λ)	χ(λ)	l(λ)
Red	0.225	0.037	0.629
Blue/Green	0.0232	0.074	0.674

The total chlorophyll concentration is the sum of the chlorophyll concentration of each plant functional type represented in the PISCES/DGOM model. Irradiance at each vertical level is calculated as follows:

$$I_{(z)} = r * I_{(z-1)} * (e^{-(kr*z)} + e^{-(kg*z)}) \quad (3)$$

Coefficient r (equal to 0.5) is introduced for splitting irradiance in two bands. We also implement the "*Self Shading*" effect of phytoplankton substituting the term of surface irradiance with irradiance of the vertical level immediately above.

Modelling

The OPA model has 2 degrees of resolution longitudinally and varies latitudinally from 0.5 degrees at the equator to 1.5 degrees at high latitudes. It is based on primitive equations and is fully prognostic. Mixing is made along isopycnal surfaces and includes the Gent and McWilliams (1990) parameterization for eddy-induced transport. Vertical eddy diffusivity and viscosity coefficients are computed from a 1.5 order turbulent closure scheme which has an explicit formulation of the mixed layer, as well as minimum of diffusion in the thermocline (Gaspar *et al*., 1990).
OPA is coupled with a biogeochemical model (PISCES/Dynamic Green Ocean Model) where 3 plant functional types (silicifiers, calcifiers and nanophytoplankton) and a full ocean carbon cycle are represented (Buitenhuis et al., this meeting; Aumont *et al*., 2003).

Future Work

Based on the encouraging results showed here we plan to further improve this new implementation. The next step should be exploring the possibility to include also the light reflection carried out by the "calcifiers" plant functional group recently introduced in the PISCES/Dynamic Green Ocean Model.

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Results

Case A) sensitivity study where all the incoming radiation is attenuated by marine biomass (equation 3).
Case B) sensitivity study where only the photosynthetically active incoming radiation is attenuated by marine biomass (equation 3 multiplied by 0.43).
Case C) estimate of simulation where the photosynthetically active incoming radiation is attenuated by marine biomass (equation 3 multiplied by 0.43) and the remaining incoming radiation is unaffected by marine biomass (equation 1 multiplied by 0.57). Unlike for Cases A and B, we have not done a model simulation for Case C but have estimated it using Case A.

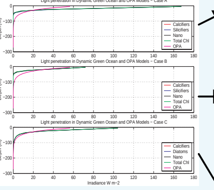

Figure 1: Penetration of irradiance calculated for Cases A (top), B (middle), and C (bottom) for single grid point in the subtropical gyre of the North Atlantic. Average annual values for year 1995.

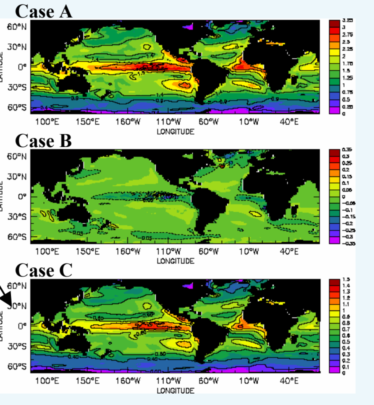

Figure 2: SST difference between Cases A (top), B (middle) and C (bottom) and the standard formulation of the OPA model. The difference is calculated in each case as SST calculated in OPA (equation 1) subtracted both to SST calculated by equation 3 (Case A) and subtracted to SST calculated by equation 3 with extra coefficient 0.43 Included to use only the Photosynthetically Available Radiation (PAR) . Average annual values for year 1995.

Discussion

We did sensitivity studies to estimate both the penetration of light in the upper ocean and SST increase. Simulations were done from 1990 to 1998. We show results for 1995. Case A study clearly shows that the attenuation of all incoming radiation by marine biomass produces an unrealistic warming of SST in some areas of the model domain (North and Equatorial Pacific and North Atlantic Ocean) (Figure 2, top). This feature is also confirmed by the remarkable difference of values of irradiance immediately below the surface (Figure 1, upper panel). On the other hand Case B study confirms that the inclusion of the 0.43 coefficient in equation 3 can dramatically affect the computation of the irradiance in the top 200 metres of the water column even cooling SST (Figure 2, middle). In fact, just below the surface (0-50 m), the values of irradiance calculated in Case B are similar to those computed by the equation 1 in OPA, but they are quickly attenuated to nearly zero at 60 m (Figure 1, middle panel). Cases A and B are two unrealistic extremes. A realistic case would consider that the attenuation of marine biomass would apply to the photosynthetically active radiation only (PAR, 43 % of incoming radiation), and the remaining 57 % of the incoming radiation would penetrate the ocean as already parameterized in OPA. Case C attempts to illustrate this more realistic surface warming. In Case C study irradiance penetration is explicitly calculated using equation 3 (with the 0.43 coefficient included) plus the equation 1 applied to the non-PAR radiation (0.57) . In order to calculate the difference of SST fields, because of lack of time, we only tried to roughly estimate the values multiplying results of case A by 0.43. Estimates of SST differences in Case C and their areas of appearance seem to be consistent with values showed by the previous modelling (Lefevre *et al*., 2001; Nakamoto *et al*., 2001) and observational (Sathyendranath *et al*., 1991) studies.

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